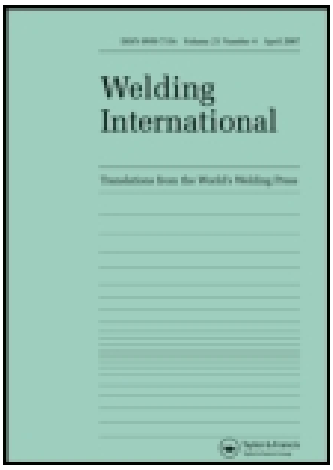

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Determination of the dimensions of the heat-affected zone in welding gas pipeline components

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Analytical decisions supported by experimental data were used to determine the dependences for calculating the size of the heat-affected zone (HAZ) in multilayer welding of circumferential joints in transmission gas pipelines. Data on the dimensions of this zone are essential for evaluating the possibility of applying cold cutting in the rejection of elements of gas pipelines because of defects in circumferential welded joints or welded joints in transition rings in the vicinity of circumferential welded joints.

Keywords: gas pipeline; heat-affected zone; welding; welded connection; calculation; dependence; experiment

At present, in major overhaul of processing pipelines in compressor stations and connecting loops of transmission gas pipelines, it is necessary to solve the problem of replacement of scarce shaped components (branches, triple joints and transition pieces) rejected in diagnostics. The connecting components are rejected in most cases as a result of the presence of defects in circumferential welded joints or in welded joints in transition rings in the vicinity of circumferential welded joints. The possibilities of repair for the removal of internal and external defects in welded joints are limited (STO Gazprom 2-2.2-136-2007, 2-2.3-137-2007). The main type of effect is the unacceptable displacement of the edges of the welded elements. In general, this type of effect cannot be removed by repair and, consequently, it is necessary to cut out the welded joint.

Application of the flame cutting method (with heating of metal) in the body of the welded joint is not permitted, and this method cannot be applied in the body of the transition rings because of the small size of the remaining element, which should not be shorter than 100 mm for gas pipelines with a diameter of less than 530 and 250 mm for pipelines with large diameters (SniP standard 2.05 0.06-85). Otherwise, defective sections should be removed by machining.

Consequently, rejected welded joints are removed in most cases by the method of cold (without heating) cutting (e.g. using machines of type HD and MS of the Clamshell series, manufactured by D.L. Ricci/H&S), which can be used to perform operations with sufficient accuracy and machine edges as required.

However, it is necessary to solve the problem of the dimensions of the removed zone adjacent to the welded joint. It is well known that welded (fusion) joints can be divided into several sections differing in the chemical composition of the metal and its macro- and microstructure, and also by other features, including the dimensions of the welded joint, the fusion zone and the length of the HAZ.

The HAZ is the section of the parent metal adjacent to the welded joint in which phase and structural transformations, resulting in the changes of the properties of the welded joints, take place as a result of the thermal effect of the welding power source in heating and subsequent cooling [1].

In steels used for the manufacture of pipes, phase transformations take place in the temperature range 800–500°C (the recrystallization zone) [2]. A transition zone (blue shortness zone) forms at a temperature of 200–500°C). In this region, the probability of occurrence of the processes of ageing of the metal is high and this results in a reduction of the toughness and ductility of the metal and increases its crack formation susceptibility.

The normalization-technical documents (STO Gazprom 2-2.2-136-2007, 2-2.3-137-2007) do not specify the possible length of the HAZ. The data on the dimensions of this zone in the removal of the defective welded joint are used to increase the subsequent service reliability of the gas pipeline components and avoid failures (especially in processing pipelines of compressor stations operating under high dynamic loading).

The general processes of manual arc welding have been studied sufficiently [1], but there is insufficient data for multipass welding of circumferential joints in transmission gas pipelines.

The aim of this study was the determination of the dimensions of the HAZ in multipass welding of circumferential joints, heated above a given temperature, in order to evaluate the possibilities of using cold cutting.

The diameter of the main welded elements of the compressor pipelines changes in the range 426–1420 mm, the wall thickness in the range 10–36 mm. Therefore, the damaged section of the pipeline cannot be removed in a single pass. The root (first) layer, placed at the top of the two-sided gap in the butt joint, fills part of the height of the joint. The filling of the welding gap in the second, third and subsequent passes takes place with breaks for dressing and preparation of the next layer of the welded joint for welding. Thus, no heat flows are applied from different sections of the produced welded joint. Therefore, the thermal calculations of the process of welding of the facing layer (deposition of the beads) are carried out using the method of the point moving source on the surface of the semi-infinite solid.

In the limiting state, the increase of temperature from the point moving source on the surface at any point with the coordinates x, y, z, is calculated from equation [1]

$$\Delta T = \frac{q}{2\pi\lambda R} \mathrm{e}^{-v/2a(R+x)}, \tag{1}$$

where R is the spatial radius vector in the moving coordinate system, i.e. the distance of the investigated point A from the origin O of the moving system, $R = \sqrt{x^2 + y^2 + z^2}$; $\Delta T = T - T_0$ (T is the temperature at the given point; T_0 is the initial temperature).

The zone of the parent metal is situated within the limits of the coordinates y (isotherms) corresponding to the given temperature and is denoted by HAZ – l (Figure 1). In this case, this zone does not depend on the wall thickness and depends only on preheating.

An example of the calculation of the temperature field on the surface of a body for a gas pipeline with a diameter of 426–1420 mm is shown in Figure 1.

To evaluate the width $2l$ of the zone of increase of temperature ΔT above the permissible temperature in deposition of a facing bead [1], it is recommended to solve two equations in the parametric form

$$\frac{vl}{2a} = \pm \frac{\rho_3}{1+\rho_3} \sqrt{1+2\rho_3} = L, \tag{2}$$

$$\frac{\Delta T_l 4\pi\lambda a}{qv} = \frac{1}{\rho_3} \mathrm{e}^{-(\rho_3/1+\rho_3)} = \Theta, \tag{3}$$

where $\rho_3 = vR/(2a)$; v is the welding speed; λ and a are the heat conductivity and thermal diffusivity coefficients of the metal, respectively; $q = \eta UI$ is the heat flow used for heating the metal (η is the effective efficiency of the heating process; in open arc welding with metallic electrodes $\eta = 0.70$–0.85 [1]).

The resultant dimensionless criterial equations are usually solved in the form of nomograms – different values of ρ_3 are specified to determine the value Θ, corresponding to different L. Knowing the welding conditions, it is possible to determine the parameter Θ and, subsequently, the parameter L from the nomograms. Consequently, the required size of the HAZ l can be calculated. This method is not suitable for engineering calculations.

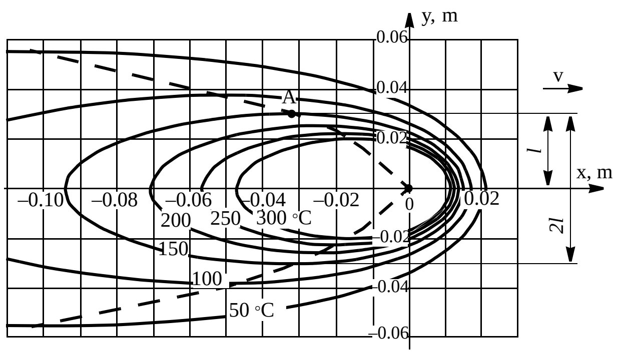

Figure 1. Increase of temperature in the limiting state in deposition of a bead of a circumferential welded joint of a gas pipeline with a diameter in the range 425–1420 mm ($q = 3200$ W, $v = 0.001$ m/s; $b = 7.820 \times 10^{-6}$ m^2/s; $\lambda = 36$ W/(m K); broken line – the line of limiting temperatures).

To obtain an analytical solution, the dependence of Θ and L was discretized by the numerical solution of the system of equations in the range $L = 1.0$–3.5 (corresponds to all investigated manual arc welding conditions) with a step of 0.1. Subsequently, the resultant numerical values of Θ_i and L_i were approximated by the exponential function $L = A\Theta^{-n}$. The parameter Θ was varied in the range 0.05–0.5. The approximation error did not exceed 3%.

The resultant dependence has the form

$$\frac{vl}{2a} = \frac{0.684}{(\Delta T 4\pi\lambda a/qv)^{0.57}}. \tag{4}$$

Consequently, the size of the HAZ on the side of one element is

$$l = \frac{1.368a}{v(\Delta T_i 4\pi\lambda a/qv)^{0.57}} = \frac{1.368a}{v((T-T_0)4\pi\lambda a/qv)^{0.57}}. \tag{5}$$

In [2], using the scheme of the rapidly acting point heat source on the surface of the solid, it is proposed to determine the width of the heated zone by the equation

$$2l = \sqrt{\frac{8q/v}{2.71\pi\tilde{N}\rho(T-T_0)}}. \tag{6}$$

To determine the dimensions of the HAZ, experiments were carried out with welding pieces of a pipe with a diameter of 1420 mm, wall thickness 19.2 mm and pieces of a pipe with a diameter of 1020 mm, wall thickness 16 mm, with a preheat temperature of 130°C. Four thermocouples were installed along the axis of the welded pieces of the pipe at a distance of 12, 15, 21 and 30 mm from the axis of the welding gap (from the centre of the welded joints) in the direction normal to the welding direction. The thermocouples were used for recording the temperature at the point throughout the entire welding

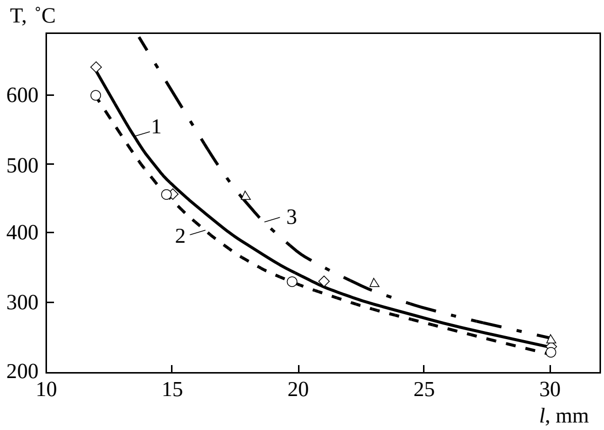

Figure 2. Dependence of the length of the HAZ on the temperature to which the metal is heated in welding pipes with a diameter of 1420 mm, wall thickness 19.2 mm ($v = 0.001$ m/s; $q = 2000$ W; preheat temperature of the body of the pipe $T_0 = 130$°C): 1, experimental data; 2 and 3, calculated from Equations (5) and (6), respectively.

cycle. Figure 2 shows the maximum value temperature measuring points.

For example, the size of the zone of the metal (from the point of contact of the electrodes), heated above 330°C, was 21 mm, calculated from Equation (5) – 20 mm, and calculated from Equation (6) – 24 mm. Similarly, the size of the zone of the metal, heated as a result of welding to temperatures above 450°C, was 15 mm, and the size calculated from Equations (5) and (6) was 15 and 18 mm, respectively.

The maximum deviation of the calculated data from the experimental values was smaller than 10% for Equation (5) and less than 19% for Equation (6) in heating of the metal to 500°C.

Conclusions

The resultant analytical solution for the determination of the size of the HAZ and the currently available equation for the rapidly moving heat source on the surface of the body with an error not exceeding 20% give approximately the same result. It is therefore necessary to select in each specific case the simpler method of the two in order to calculate the size of the removed zone, adjacent to the defective welded joint, to ensure that in addition to the defective welded joints, the zone of the parent metal with the lower mechanical properties is also removed.

To determine the feasibility of using cold cutting of shaped components, it is important to take into account the requirements on connecting components of pipelines (STO Gazprom 2-4.1-273-2008).

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